Water reuse and zero liquid discharge: a sustainable water resource solution

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Abstract Increased water demand from population and economic growth, environmental needs, change in rainfall, flood contamination of good quality water and over abstraction of groundwater are all factors that will continue to create water shortage problems. This paper considers alternative solutions, which conform to sustainable solution premises whilst being economically beneficial to the community. The importance of pilot studies is reviewed and the surprises they can uncover. Case studies describe the benefits of long-term operating experience of zero discharge systems reusing the wastewater produced by car manufacture and secondary sewage reuse for a large coal fired power plant. Applications of reuse on large islands such as Hawaii and desert communities are discussed including the production of cash crops with high efficiency irrigation systems by reusing brackish municipal wastewater. Large municipal zero discharge potable water production is also described with an economic comparison of the alternatives.

Keywords Aquifer recharge; effluent reuse; hybrids; integrated pollution prevention control; reuse for industry; zero liquid discharge

Introduction

The European Union (EU), national governments and leading institutions are promoting sustainable environmental solutions as the best way to continue economic development. Water shortage problems due to change in rainfall, flood contamination of good quality water and over abstraction of groundwater are becoming more widespread. These changes combined with new legislation are encouraging the development of sustainable water resource strategies. The EU’s policy includes the promotion of treated wastewater reuse and many governments and regulators are providing financial incentives to promote this beneficial strategy.

Zero Liquid Discharge (ZLD) has been regarded for many years as an uneconomic solution. However, the challenge of population growth and scarcity of water has brought a sharper focus on the development of ZLD technologies, such that new, more cost-effective options are now available. Furthermore, there is long-term practical experience available to developers of new industrial plants and for the optimisation of existing plants. This experience includes innovative solutions in production and municipal industries. The case studies below consider the issues on the selection of treatment processes to ensure a reliable ZLD water management system.

Design issues

The benefit of ZLD is that water demand and discharge to the environment can be almost stopped or dramatically reduced. A drought proof and reliable solution can be implemented that attracts tax or financial incentives of up to 60% of the capital value in some regions due to the benefit to the environment and the local community. The EU wide integrated pollution prevention control legislation (IPPC), an environmental operational
license for industry encourages serious deliberation on longer-term decisions on water and wastewater solutions. This applies where the legislation is being enforced or financial incentives are available. When an industrial facility has been discharging to a municipal wastewater sewer or to a surface discharge, there will often be limited available data on the quality or quantity of the wastewater that are needed to design a ZLD system. This can create surprises when the wastewater is treated and reused unless detailed site audits and pilot studies are completed. Free or very low water and wastewater costs are difficult to compete with, as they do not consider the actual value of water or its environmental impact. The same applies where there is a lack of environmental quality standards, legislation or enforcement. On the other hand it is also important to design for short to medium term legislation even if it is leaving space for future treatment stages and taking a phased approach. Other issues that need to be carefully investigated include:

(a) reducing water demand through improving water management  
(b) reducing demand by reusing internally as determined by pinch analysis  
(c) controlling the quality and quantity of the wastewater to be reclaimed  
(d) ensuring a drought proof supply  
(e) ownership agreement of the municipal wastewater to enable industrial reuse  
(f) agreed water quality standards to ensure fitness for purpose  
(g) good co-operation between regulators so that water, waste, environment and public health issues can be agreed.

If the initial feasibility demonstrates a benefit, then running a comprehensive pilot study is the key to a successful project. The pilot study should achieve the following:

(a) understand the feedstock  
(b) identify design issues and risks  
(c) design, operate and optimise the process train  
(d) help the site to understand its waste and how they can influence production to minimise wastewater treatment costs  
(e) build the site’s confidence in the solution  
(f) repeatedly test and evaluate design improvement to minimise life cycle costs  
(g) develop realistic process and operational guarantees

Pilot studies take time and are expensive but can save up to 30% of the life cycle cost. ZLD systems are invariably comprised of multiple processes which all have to work harmoniously. The risk of one process failing, and compounding problems must be addressed with contingency equipment or procedures, including, at the very least, diversion tanks that can hold wastewater while a problem is remedied. ZLD, taken literally and 365 d/yr, can be a daunting challenge. This is where multi-process design and operating experience is critical when combined with reliable data from a well run pilot study.

Case studies

Car manufacturing
Daimler Chrysler has multiple manufacturing plants in Mexico. The water resources in Mexico are similar to many areas of the Mediterranean region with over-abstracted aquifers and regular droughts. Daimler Chrysler has over 6 years of operating zero discharge wastewater treatment systems at their plants in Saltillo and more recently at Toluca (Zacerkowny, 2001). General Motors has also reused its wastewater at their plant at Ramos Arizpe and was awarded the prestigious Stockholm Industry Water Award for 2001 for their environmental management techniques.

The Toluca project, 37 miles north of Mexico City was initiated in 1998 to build a zero liquid discharge wastewater facility to reduce the demand on the local aquifer. The decision to implement this project was based on the experience from the other sites in Mexico. The
system treats all the wastewater from the plant with no liquid discharge to the environment, while at the same time reducing manufacturing costs.

ZLD is saving in excess of 1 million € per year in water and waste charges. The manufacturing plant has halved its water costs while doubling the amount of water available for production expansion. This has been achieved without increasing the demand on the limited groundwater supply. Approximately 900 m³/d (95% of the water used for manufacture) is recovered and reused. Sewage and domestic wastewater are biologically treated and sludge is digested and dewatered for fertiliser production. Industrial wastewater from the machining plant and assembly plants are pre-treated separately for oil removal and metals precipitation. The industrial wastewater is then blended and biologically treated, sand filtered and treated by reverse osmosis (RO). RO concentrate is microfiltered and retreated in a second stage RO to further reduce the waste stream flow. RO reject from the second stage is evaporated in a crystalliser – with the distillate being recovered, while the salt cake is landfilled. This system is similar to other installations in the automotive, power and paper industry.

Similar projects are being considered and implemented in Europe with the introduction of IPPC which can attract various financial incentives depending on the country, the environmental benefit of reuse and the elimination of environmental discharge. These projects include the collection and use of rainwater to minimise potable and ground water usage.

**Power generation**

Eraring Power’s 2640 MW ZLD coal-fired power station, in New South Wales, Australia is saving approximately 0.6 million €a year through reusing secondary effluent for power plant use. The potable water supply to the station became unreliable due to increased demand and climate change. Secondary effluent from a nearby sewage treatment plant needed to be discharged through a long sea outfall and was available for reuse. The best solution for the power station and municipality was to bring the secondary effluent to a standard suitable for the boiler feed to the power station. The power plant now treats secondary effluent through Continuous Microfiltration and RO for ultimate use as high-pressure boiler feed at an internal cost of 0.12 €/m³. RO reject is discharged to the ash pond.

This reuse application could be competitive with groundwater based on recent reports on groundwater abstraction costs in North Africa at 0.10–0.20 €/m³ (IFC, 2002). Reclaimed water replaced 74% of all water used in the period July 2000 to June 2001. This was lower than expected due to drought and the lack of effluent from the local community. Since the reclaim water has a lower total dissolved solids (TDS) content than the previously used city water, approximately 150 ion exchange regenerations per year have been eliminated, equivalent to over 85 tons of sulphuric acid and 124 tons of caustic soda. The plant was commissioned in March 1995 (Craig, 2001).

This experience has been of real value to the new gas fired power station developments in the USA where fast build is essential and environmental compliance is severe. Electing to develop a ZLD facility has the dual benefit of expediting the power plant schedule, achieving commercial operation quickly, and being a good environmental neighbour to the local community. The new stations such as Constellation Energy Group’s new 750 MW High Desert Power project in California is being built as a ZLD facility recovering and reusing over 95% of the wastewater from the site rather than discharging to the environment. Aquifer storage and recovery (ASR), referred to as “aquifer banking”, will be used to overcome water shortage during summer months.

Raw water from the Mojave Water Project is treated in an Actiflo ballasted floc clarifier and used for cooling tower makeup, with a proportion of the clarified water being further treated by media filter, granular activated carbon and ultrafiltration prior to ASR. Boiler
feed water is treated through continuous deionization CDI polishers that use electricity rather than chemicals for regeneration, important in a ZLD facility. Cooling tower blowdown is processed by microfiltration softening and two stage RO. The RO reject is sent to a crystallizer, with the resulting distillate being reused and the salt cake disposed off site.

Islands and desert communities

Honouliuli, Hawaii. This is one of the largest and most innovative new wastewater projects utilising a public-private partnership to recycle 45,360 m³/d that began operation in August 2000. In the mid 1990s, city planners were faced with a federal consent decree demanding that the City and County of Honolulu recycle a minimum of 37,850 m³/d by July 2001. This decree was due to a series of needed but delayed improvements within the wastewater system. This partnership includes the following scopes.

(a) Design, Build and Operate a tertiary treatment system with sand filters and UV disinfection with Vivendi Water technology for the production of R1 – Unrestricted Reuse Water. The feed source is the City and County’s 106,000 m³/d Secondary Wastewater Treatment Facility. Treated water is used in golf courses, highway greenbelts and cooling tower applications.

(b) Design, Build and Operate of a 50 km R1 pumping and distribution system.

(c) Design, Build Operate an integrated membrane system with microfiltration and reverse osmosis to repurify the wastewater to produce boiler feed water for multiple power generation and oil refinery customers.

(d) Design, Build and Operate a RO pumping station and 13 km delivery system.

(e) Plant operation marketing and distribution of the tailored water products for a 20 year period.

Fiscally the project saved over 35% utilising a design/build approach to the construction. Additionally the project saved an additional 52 M€ (48 M$) over the contract term as a result of Vivendi Water developing water purchase contracts with 7 private water users. These users included refineries and power supply facilities. The benefits to the community include that 45,000 m³/d of potable water was made available for drinking, alternative competitive water was made available for industry and extending the life of the long sea outfall by reducing the flowrate to sea.

This project is similar to the NEWater projects in Singapore that uses microfiltration and RO technology to treat wastewater and use it as an alternative to city water for industry. Projects include the Sony Display Devices, Bedok and Kranji plants that supply NEWater for wafer fabrication plants. Singapore’s plan is for 25% of the total demand to be produced from repurified NEWater by 2012. At present industry accounts for half the islands water consumption (Water desalination report, 2002; Okazaki et al., 2000).

Canary Islands. In some Mediterranean regions, 58% of coastal aquifers suffer from saline ingress. (EEA, 2000). Over abstraction of groundwater results in rising salinity of the well water due to saline ingress. This has caused 25% of the irrigated agricultural land to be salinised in some areas. Soil salinisation severely restricts agricultural industry, stops local food production and creates unemployment. This is a global problem with 10% of global water usage being sourced from over abstracted groundwater. It is estimated that 20% of global irrigated agricultural areas have been salinised (Cosgrove et al., 2000).

RO desalination has been selected by the Canary Islands to satisfy the demand from tourism development since the 1960s. On some islands desalination is the only water resource available along with brackish wastewater desalination using RO. High efficiency, energy recovery systems have dramatically reduced energy requirement for membrane treatment systems. Energy efficiency and membrane costs have reduced production costs
from > 5 €/m$^3$ to 2–0.5 €/m$^3$ for seawater and 0.5–0.25 €/m$^3$ for wastewater repurification for irrigation or aquifer recharge as an indirect potable water source. (Operating costs depend on the size of the system, cost of power, water salinity etc.). As a result of the reducing groundwater availability, seawater desalination and reuse has grown dramatically to satisfy demand for the important tourist industry.

Water reuse in Spain has also increased significantly, with disinfected tertiary effluent and desalinated brackish secondary effluent being reused. Over 400 desalination plants have been installed for agricultural irrigation in Spain. Currently a 120,000 m$^3$/d seawater RO plant is being installed in southern Spain for this use (San Juan et al., 2002). One serious problem is caused by seawater infiltration into the sewerage system before biological treatment in low-lying areas so that the secondary effluent has too high a salinity for irrigation. Brackish secondary effluent is an attractive and valuable water resource to be reclaimed, as an alternative to coastal discharge. The reclaim of brackish secondary sewage costs substantially less than seawater desalination and is being used reliably in multiple sites in the Canary Islands and other areas. The reclaimed water feeds highly efficient irrigation systems in a controlled environment. Cash crops grow in manmade soil on seed beds supported above the salinised soil.

Saline ingress control with repurified wastewater has been used for over 25 years in California. This application also includes aquifer recharge as a source on indirect potable water. The Orange County Water District in California has just started a 330,000 m$^3$/d aquifer recharge expansion project as a lower cost and proven high quality option to importing fresh water based on 25 years operating experience and many years of pilot studies.

**Potable water production - ZLD**

Following the outbreak of cryptosporidiosis in West Cumbria, UK in 1993 associated with the water supply, United Utilities embarked on a plan to provide a robust and reliable barrier to *Cryptosporidium*. Historically, the water sources in this part of North West England have been classified as high quality i.e. low turbidity and colour. Consequently, only coarse microstraining followed by disinfection with chlorine and pH elevation with lime has been required to comply with the EC drinking water directive.

The plant had to be designed for ZLD as there is no sewer or surface drain to dispose of the washwater at Ennerdale. The primary washwater from the CMF microfiltration system is recovered to produce potable water by a secondary microfiltration system. Wastewater from the secondary units is processed in a sludge thickener before being tankered off site to the nearest sewage treatment works. The water recovery efficiency is 99.5 to 99.9% with only 0.1 to 0.5% of 59,000 m$^3$/d being removed by tanker approximately once every two weeks (Hillis, 1999).

This ZLD microfiltration system has been installed on multiple sites treating flowrates up to 126,000 m$^3$/d where environmental standards prevent waste products being discharged into surface waters or there is a need to maximise the productivity due to water shortage. The growth of large microfiltration and ultrafiltration installations has been dramatic. The cumulative growth in the volume per day treated is in the order of 500% over the last five years. Potable water quality standards and legislation for efficient removal of pathogens such as *Cryptosporidium* and *Giardia*, as well as the recognition of the sustainable benefits of reuse have driven this growth. There are over 20 membrane-based water reclamation plants in the USA built or under construction treating 670,000 m$^3$/d (Freeman, 2002) along with almost the same wastewater volume per day in the rest of the world. Some 62% of the USA projects and 85% of the flowrate is treated using USFilter, Vivendi Water technology. Many of these systems incorporate the integrated membrane solution of CMF or CMF-S microfiltration and BWRO.
This rapid growth in membrane treatment and integrated membrane systems has reduced the life cycle costs and increased the competitiveness of this solution. Recent process designs termed “hybrids” take advantage of these developments by combing the benefits of membrane desalination with thermal power generation and wastewater reuse for aquifer recharge to reduce production costs even further.

**Economic comparison**
The economic benefits to the community have to be calculated based on local priorities and costs. A sustainable water resource solution or a tailored Integrated Water Resource management (IWRM) approach as promoted by Global Water Partnership (Agarwal et al., 2000) is needed to add the maximum benefit to the community. Typical benefits that support the economy include:

(a) planning for a sustainable future requires a reliable knowledge of resource available, recharge, future demand and a positive involvement of the community
(b) increasing the availability of potable water and reducing the water cost by repurifying wastewater for industry and irrigation
(c) providing a drought proof water resource through reuse
(d) growing cash crops and creating employment in areas blighted by soil salinisation
(e) positively controlling saline ingress and recharge aquifers to create a sustainable water resource
(f) reducing wastewater disposal to sea and protecting bathing beaches
(g) supporting the tourism industry through irrigation of landscapes and golf industry with repurified water.

The actual costs depend on many variables such as the complexity of the design, level of automation, salinity of the water, cost of energy and finance, subsidised fuel prices, environmental impact costs, government or environmental grants available, the size of the system and the reliability of the design data (see Table 1). Well designed and run pilot studies naturally help to reduce oversights, and minimise the whole life costs while reducing the operational risks.

**Conclusions**
Integrated water resource management needs a holistic long-term approach. This must be supported by legislation, agreed quality standards and international finance to enable projects to be realised. This is helped by one government water agency being responsible for all water resource issues – from fresh water to wastewater treatment – rather than separate regulators responsible for single parts of the total solution. The only solutions to water shortage are to maximise the efficiency of water management, reclaim and reuse, desalinate or to import fresh water. The increasing global experience in small and large high efficiency systems is continually reducing the production costs. The operation of ZLD systems that include wastewater reuse for industry or high efficiency irrigation and aquifer recharge provide long-term experience of drought proof and robust water resource solutions as the weather patterns continue to change. These innovative solutions enable coastal cities as well as Mediterranean islands to move towards ZLD as part of an integrated water resource management strategy.

**Table 1** Production cost summary

<table>
<thead>
<tr>
<th>Application</th>
<th>Typical operating costs €/m³</th>
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<tbody>
<tr>
<td>Groundwater abstraction</td>
<td>0.10–0.20</td>
</tr>
<tr>
<td>Secondary sewage CMF – RO 0.</td>
<td>12–0.25</td>
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<tr>
<td>Seawater desalination (SWRO)</td>
<td>0.50–2.00</td>
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References


